Reply to Comment on "Analysis of the spatial distribution between successive earthquakes"

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This is a reply to the Comment on "Analysis of the spatial distribution between successive earthquakes" by Maximilian Jonas Werner and Didier Sornette.

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Werner and Sornette (WS) [1] claim to show that our analysis of spatial distances between successive earthquakes in southern California [2] does not allow to detect length scales associated with aftershock zones. However, almost all of their arguments are based on an analysis that is completely insensitive to finite size scaling: A function F obeys finite size scaling if and only if a function f and constants α and β exist such that $F_L(x) = L^\alpha f(x/L^\beta)$ for any (large) system size L. While we studied the probability density function (PDF) $P_L(\Delta r)$ of spatial distances over all boxes of a given linear size L and its variation with L, WS do not take into account any variation with box size. Instead, they consider all events in the given catalog being in a single "box" whose size and shape is determined by the catalog. Since the scaling function f is not constrained to a particular form *a priori*, the presence or absence of finite size scaling cannot be established by considering a single scale L as claimed by WS. Thus, they cannot make any statements about the variation with linear size L and the existence of finite size scaling, which is a crucial point in our line of argument regarding aftershock zone scaling with main shock magnitude. In particular, this is true for their results obtained for earthquake catalogs from Northern California and Japan.

In fact, the results they obtained are strikingly similar to results for periods of quasi-stationary seismic activity [3]. This suggests that the observation periods in Japan and Northern California that WS analyzed show rates of seismic activity which are rather homogeneous compared to the period we analyzed for southern California (1984-2000). As we emphasized in Ref. [2], the power law behavior of $P_L(\Delta r)$, for earthquakes in Southern California, only holds for *very long* observation periods where the rate of earthquake activity is highly heterogeneous in *space and time*. This was confirmed in a detailed study in Ref. [3]. The particular combination of periods and regions with high seismic activity and low seismic activity in southern California is the reason for observing the scale-free PDF for spatial distances. Thus, considering only the most active period around the Landers event, or neglecting it, is expected to lead to strong deviations in the PDF as observed by WS. In particular, their results do not in any way contradict the results we found and our discussion emphasizing the difference between homogeneous and heterogeneous rates in [2].

Another point raised by WS is that aftershocks occur at distances larger than the main shock's rupture length. This is well-known, yet the vast majority of what are typically considered aftershocks occur within distances which are comparable to and no more than a few times the rupture length (see, for example, Ref. [4] and references therein). In particular, the largest rupture length in the catalog from southern California we studied is $\approx$ 90km. This is significantly less than the spatial extent of the area studied ($\approx$ 500km) which allows us to test the hypothesis of aftershock zone scaling with magnitude. As our results in Ref. [2] show, no physical length scale exists in the range from 20 km to $\approx$ 500km.

WS also present results for a spatially extended version of the ETAS model. While they claim that this extended model is an accurate description of aftershock zone scaling with main shock magnitude, a comparison of the Landers sequence shown in their Fig. 1 [1] and the ETAS model in Fig. 2 [1] suggests otherwise. More importantly, the particular form of $P(d)$ is speculative — it does not follow from the work by Kagan [5] — and it is by no means generally accepted. Despite some indication for a power law with $\mu \approx 1.35$ for *short* times after the mainshock [6], other results even directly contradict the form of a power-law decay for distances larger than the main shock rupture length [7, 8] if the activity is considered over the long time scales relevant for our study in Ref. [2]. To summarize, the behavior of a model, which is not an accurate description of aftershock zone scaling, cannot prove that our earlier results are insensitive to the existence of physical length scales associated with aftershock zones.

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